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Stream nutrient levels and proximity of agricultural and forest land to streams: Some relationships

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ABSTRACT: The effectiveness of forested buffer strips for controlling nutrient loss from agricultural land to streams is not well documented. To clarify this effectiveness, an attempt was made to determine whether considering the proximity of two land use types (agriculture and forest) to streams improved the ability to predict nutrient levels over simply using the proportion of watersheds occupied by each land use. Results indicated that considering the proximity of these land uses did not improve this predictive ability. One reason may be that the long-term effects of near-stream vegetation in reducing stream nutrient levels is negligible.

THE areawide waste treatment management program spelled out in Section 208 of Public Law 92-500 (as amended) was intended in part to identify agricultural and silvicultural nonpoint sources of pollution and to establish procedures and methods for controlling pollution of surface waters from these sources. However, many people in the agricultural community are understandably concerned that the efforts to satisfy requirements in Section 208 that center on erosion control and use of good farming practices are without a sufficently sound research base (*26*). Although most are fairly confident that adoption of state-of-the-art practices designed to maintain agricultural production and help achieve water quality goals will help conserve soil, water, plant nutrients, and pesticides, they cannot be sure that such practices will measurably improve surface water quality without better scientific evidence (*26*).

The primary objective of our study was to help satisfy those concerns by clarifying the effectiveness of forested buffer strips in reducing nutrient levels in streams draining agricultural lands. Specifically, we attempted to provide insight as to whether forested buffer zones might appreciably reduce nitrogen (N) and/or phosphorus (P) levels in streams.

To accomplish our objective, we compared stream nutrient concentrations from sets of 80 and 175 relatively large watersheds having varied patterns of forest and agricultural land use.

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Literature review

Although many studies have focused on characteristics of runoff from agricultural lands and possible contributions of agricultural practices to stream nutrient levels, little attention has been directed to the effects of forested buffer strips on reducing stream nutrient levels under normal watershed-scale (vs. field- or plot-scale) conditions. Moreover, there is considerable disagreement in results and conclusions from one study to another.

Probably the best reviews on the subject are by Karr and Schlosser (*16, 17*). Their work included evaluations of existing data from the literature regarding the ability of nearstream vegetation to reduce nutrient transport from terrestrial to aquatic components of agricultural ecosystems. Among their conclusions, they stated: "Even at high efficiencies of nutrient removal, in some agricultural areas surface filters acting alone may not control eutrophication because of the inputs of nutrients into streams via subsurface pathways."

Karr and Schlosser (*17*) also pointed out the probable importance streamside vegetation may have because of its potential for lowering water temperature and reducing nutrient availability and assimilation.

Most studies on the characteristics of agricultural runoff and the contribution of various agricultural practices to stream nutrient levels agree that the largest share of the nutrients leaving cropland appear to be associated with sediment (*1, 4, 9, 11, 13, 15, 16, 18, 19, 20, 21, 27, 30*). As a result, there is a common supposition that if erosion from agricultural areas is controlled by vegetative strips (among other means), sediment and nutrient input to streams will be reduced appreciably. But, as mentioned, the results and/or conclusions of these studies differ considerably.

Conclusions from the Black Creek Project in Indiana (*20, 27*) are typical in suggesting that the most effective way to control losses of P and N from agricultural lands is to control soil erosion. However, the Black Creek investigators noted that the picture was not as clear for N as for P and concluded that nitrate losses could be reduced by proper timing of fertilizer applications, using a nitrification inhibitor with fertilizer, or, in extreme cases, limiting fertilizer application (*20*).

Although generally subscribing to the idea that erosion control will reduce nutrient levels in receiving waters, a few investigators have observed situations or reviewed data that suggest possible contradictions to this contention (*5, 9, 12, 14, 22, 23, 29*). Frere (*9*), for example, while stating that erosion control practices are likely to alleviate most water quality problems regarding P and many problems regarding N, cites specific instances where nutrient levels increased as a result of no-till farming and terracing. He noted that the state-of-the-art on the effectiveness of management practices for controlling

nutrient losses has not reached the same level of understanding as that of controlling runoff and erosion. More importantly, he warns that because of this lack of understanding and these examples of negative secondary effects, persons who make management practice recommendations should be aware of the possibility of creating a problem while solving another.

In a paper addressing the sources of P in streams and lakes, Holt, Timmons, and Latterell (*12*) pointed out that large quantities of P can be supplied to surface waters as a result of leaching of vegetation. After noting that the amount of P taken up by a crop is directly related to the quantity available, they made the following observation: "...one might conclude that the phosphorus in runoff waters can be increased by the indirect effect of fertilizer due to subsequent leaching of the vegetation by precipitation." Following this line of reasoning, we feel that vegetative buffer strips in cropland areas are likely to intercept suspended sediment in runoff, and the vegetation in the buffer strips may take up more nutrients (from intercepted sediments) and subsequently lose more nutrients through leaching. Hence, the streams protected by the buffer strips would probably contain less sediment but might not have appreciably lower nutrient levels over the long term.

Still another group of studies suggests that a large percentage of nonpoint-source nutrients reach streams in soluble forms and are not associated with sediment (*2, 5, 6, 7, 8, 25, 28, 31*). Correll and others concluded that there was no significant correlation between the quantity of sediment and nutrient concentrations in runoff from their study area (*5, 6, 7*). A two-year study of three watersheds [varying in size from 4.4 to 10 km^2 (1.7-3.9 sq. miles)] in northern Florida revealed higher concentrations of dissolved inorganic P in a stream draining a forested/agricultural watershed (about 50% in each land use) than in streams draining areas classified as urban and suburban (*2*).

Rimer and associates (*25*) found a similar relationship in central North Carolina. They noted that P levels appeared to be closely associated with suspended sediment concentration except in the stream draining the only rural, "low activity" watershed in their study. Specifically, the land use in this particular 57-square-kilometers watershed consisted of forest and agriculture without major roads or significant development. These investigators felt that this stream had the lowest peak suspended sediment concentration and the highest peak P concentration because much more P was being applied to the land in agricultural use than to the land in other uses.

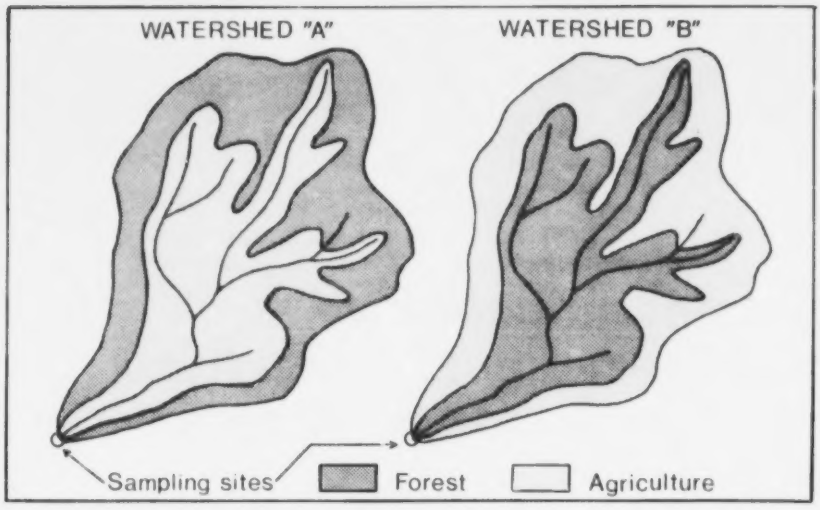

Figure 1. Contrasting hypothetical watersheds illustrating proximity of land use to streams.

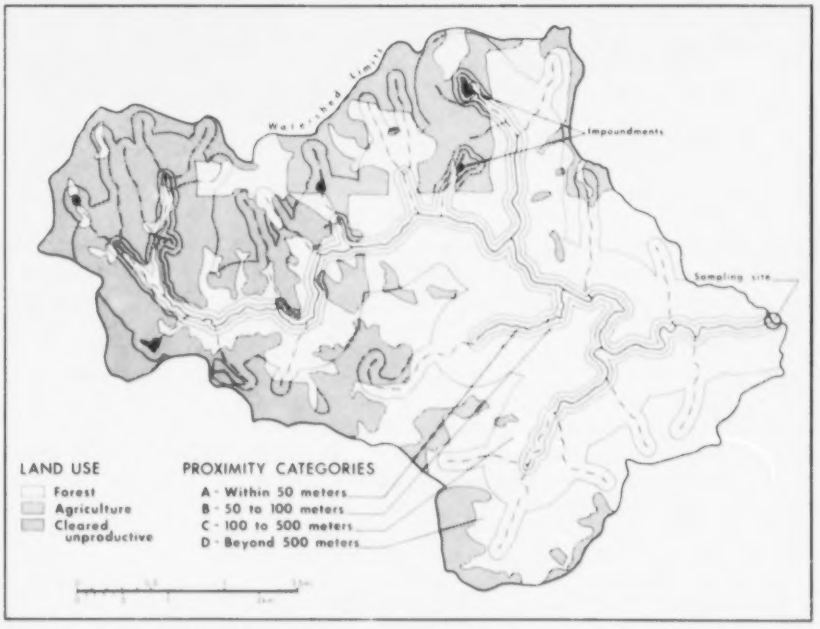

Figure 2. Typical NES/NPS watershed for which general land use and proximity to main stream categories have been delineated.

The NES/NPS study

From 1972-1973, the Environmental Protection Agency (EPA) conducted the National Eutrophication Survey (NES), which included monthly sampling of more than 4,000 sites on streams tributary to 800-plus lakes and reservoirs of interest to EPA and the states (*10*). Of these tributary sites, 904 that drained watersheds not affected by point-source pollution were selected for a study of relationships between land use and stream nutrient levels (*24*). These nonpoint-source (NPS) watersheds were relatively large—averaging 40 square kilometers (15.4 sq. miles) and ranging from 5 to 125 square kilometers (1.9-48.3 sq. miles) and located throughout the conterminous United States.

Although the NES/NPS study examined the effect of land use and other watershed characteristics on stream nutrient levels, it did not consider the importance of the proximity of contributing and noncontrib-

uting land uses, such as agriculture and forest, respectively, to streams. That is, if one considers two hypothetical watersheds, each with half its land in forest and half in agriculture, but with one having agricultural land near the main streams and forest land in the interfluves (watershed A, Figure 1) and the other having the reverse land use pattern (watershed B, Figure 1), and assuming that all other natural and anthropogenic factors equal, which of these watersheds would likely have higher stream nutrient concentrations measured at the sampling sites?

Many watersheds in the NES/NPS study data set exhibited land use patterns similar to these two hypothetical watersheds and, therefore, presented a unique opportunity for studying buffer-strip effects on stream nutrient levels. In addition, unlike many watersheds used for nutrient runoff studies, the NES watersheds were chosen without prior knowledge of nutrient losses, changes in land use, or fertilizer application rates, nor were there changes made in land use because of this project. The stream nutrient levels at the downstream end of these watersheds reflect the composite effect of all the spatial and temporal interrelationships.

Study methods

We used the following criteria to select NES watersheds for studying the importance of the proximity of contributing and noncontributing land use in determining stream nutrient concentrations:

1. *Presence of both forested and agricultural land use types.* If a watershed was mostly forested, at least 3 percent of it had to be in agriculture. Conversely, if a watershed was mainly agricultural, at least 3 percent of it had to be in forest.

2. *Complete coverage by 1:24,000-scale (7-1/2') topographic maps.*

3. *Watershed size between 25 and 55 square kilometers* (9.7-21.2 sq. miles). This criterion was merely to reduce the number of watersheds to meet time and manpower constraints.

A total of 175 watersheds met these criteria.

We developed the following scheme to categorize land use relative to proximity to main streams:

Proximity category A: The area within 50 meters (54.7 yd.) of all perennial streams and second-order[1] or higher intermittent streams.

Proximity category B: The area beyond 50 meters, but within 100 meters (109.4 yd.), of all perennial streams and second-order or higher intermittent streams.

Proximity category C: The area beyond 100 meters, but within 300 meters (546.8 yd.), of all perennial streams and second-order or higher intermittent streams, and within 100 meters of first-order intermittent streams.

Proximity category D: The remaining portion of the watershed not included in proximity categories A, B, or C.

These proximity categories were delineated on overlays to topographic maps for each watershed. Land use overlays, compiled for the original NES/NPS study, were then registered to the proximity category overlays and the percentages of each land use type in each category were computed and entered on coding sheets. Figure 2 shows an example of the combined information from the two overlays at a reduced scale.

Results and discussion

We tested the importance of proximity of general land use types to main streams in affecting mean annual stream nutrient concentrations by comparing the following two models:

$$E\ \ln C = \beta_0 + \sum_{i=1}^{3}\sum_{j=1}^{4} \beta_{ij} P_{ij} \qquad [1]$$

$$E\ \ln C = \alpha_0 + \sum_{i=1}^{3} \alpha_i P_i \qquad [2]$$

where E ln C is the expected natural log of the mean annual stream nutrient concentration, i represents land use types (1 = forest; 2 = agriculture; 3 = urban), j represents proximity to stream (1 = category A; 2 = category B; 3 = category C; 4 = category D), P_{ij} is the proportion of the total watershed area included within land use type i and proximity category j, and P_i is the proportion of the total watershed area included within land use type i.

Model 1 assumes that the mean annual nutrient concentration in streams is a function of the proportions of the different land uses in the watershed as well as the proximity of the use types to the streams. Model 2, on the other hand, assumes that the stream nutrient concentration is only a function of the proportions of the different general land uses in the watershed. Nutrient concentrations in streams are known to be log-normally distributed, so the quantity ln C is normally distributed and standard regression techniques were used to estimate the parameters and test the models.

A measure of the predictive capacity of these models is the quantity R^2 that is the proportion of the total variability accounted for by including the independent variables P_{ij} or P_i in the models. Table 1 presents a comparison of R^2 values for models 1 and 2 for each nutrient and nutrient form.

The regression coefficients are generally much lower than those reported for the land use/nutrient concentration models in the original NES/NPS study (*24*) because analyses in the original study were regionalized. The data set in our study was not separated into regions because of its lesser size.

To determine if the difference between the two models was statistically significant, we completed the following test of hypothesis for each nutrient form:

$$H_0: \beta_{i'} = \beta_{i'} = \beta_{i'} = \beta_{i'} \qquad [3]$$
$$H_a = \text{some inequality}$$

If the hypothesis is true, then model 1 is no better than model 2. To test the hypothesis we used a standard F-test. Table 2 gives the F-values for each nutrient. We then compared these F-values with the critical value, F (9, 171), 0.05 = 1.88 (0.1 = 1.63 and 0.25 = 1.27). The only nutrient form for which the hypothesis could be rejected was total N, and in that case the difference in R^2 values was only 2 percentage points.

In addition to the regression analysis, we conducted a second, less sophisticated test of the importance of proximity. Land use overlays for each of the 904 NES/NPS study watersheds were studied for disproportionate patterns of agriculture or forest in proximity to main streams (Figure 1). We selected 80 such watersheds as the most disproportionate. Many were mostly agri-

[1]Stream order was determined from blue lines on U.S. Geological Survey topographic maps (1:24,000 scale).

Table 1. Comparison of R^2 values for models (1) and (2).

	Total P	Ortho P*	Total N†	Inorganic N‡
Model 1: Land use and proximity	0.46	0.39	0.59	0.50
Model 2: Land use	0.41	0.34	0.57	0.47

*Soluble reactive phosphorus.
†Total Kjeldahl-N + NO_2 + NO_3.
‡NH_3 + NO_2 + NO_3.

Table 2. F-values* for test of hypothesis comparing models (1) and (2) (Ho: proximity of land-use types increases predictability).

Total P	Ortho P	Total N	Inorganic N
1.42	1.39	2.77	0.99

*Critical F-values for different significance levels (0.05, 1.88), (0.1, 1.63), (0.25, 1.27).

cultural with gallery forests lining a large percentage of major streams, whereas others contained mostly forested interfluvial areas and agricultural stream bottomlands without extensive gallery forests or green-strips. There were no study watersheds with all main streams lined by forests and all interfluvial areas in agriculture. Conversely, there were no watersheds where the reverse pattern occurred. Such patterns seldom, if ever, occur unless created by a conscious human effort.

There were, however, 56 study watersheds where a greater percentage of area along and near streams was in forests compared to the percentage away from streams that was largely agricultural. These watersheds seemingly would have potential nutrient filters naturally occurring between a large portion of the agricultural land and main streams. We expected streams draining these watersheds to have lower nutrient concentrations than streams draining watersheds with less forested land in close proximity to streams but with equal overall percentages of forest and agriculture land use.

On the other hand, 24 of our study watersheds had a disproportionately large amount of agricultural land in close proximity to main streams compared with the amount of agricultural land located further away from the streams.

Therefore, our second test of the importance of proximity was to compare measured mean annual stream nutrient concentrations on all 80 of these disproportionate watersheds with concentrations predicted using the regional models of the original NES/NPS study (*24*). These models did not consider proximity of agriculture or forest land use to main streams, only the percentages of total watershed areas that these land uses comprised.

The results of this comparison revealed that the number of type "A" watersheds with streams having measured nutrient concentrations higher than predicted concentrations was not significantly greater than the number with lower measured concentrations (Table 3). Moreover, the type "B" watersheds did not generally yield lower measured nutrient concentrations than predicted concentrations based solely on the percentage of total area in agricultural use or in forest. Even a detailed analysis of the deviations of measured values from predicted values was fruitless in revealing apparent relationships.

These comparisons, along with the preceding regression analyses, suggest that proximity of forest and agriculture to main streams does not bear a significant relationship to stream nutrient concentrations beyond that attributable to the proportion of the total watershed that these land uses comprise. Furthermore, considering these results, together with the observations and/or warnings of others (*9, 12, 25*), one might question the belief that forested buffer strips along streams in agricultural areas appreciably reduce nutrient levels in these streams. Granted, these streams are likely to experience lower sediment levels, lower maximum temperatures, and lower peak flows because of the buffering effect of the near-stream vegetation, but substantially lower stream nutrient levels might only be expected for the short term. Over the years, an increasing percentage of the nutrients associated with sediment intercepted by the buffer strips should eventually find its way into the "protected" streams as dissolved nutrients via subsurface pathways. In forests, once storage pools of nutrients reach a steady state, nutrient outputs must equal nutrient inputs (*32*). This may also be true for forested buffer strips once they reach maturity and/or a nutrient saturation point.

It is important to recognize, however, that our analyses did not consider unmapped stream channels or the possible use of near-stream forested areas by cattle from adjacent agricultural land. The nutrient filtering efficiency of near-stream vegetation or buffer strips may depend on consideration of the densities and patterns of unmapped drainage ways as well as use of these buffer areas by potential nutrient contributors. Another caveat worthy of mention is that by using a data set for which only monthly samples were available we may have missed some of the nutrients in storm runoff, particularly in type "A" watersheds. This may only be a local problem, however, because discharge/nutrient concentration relationships appear to vary considerably from one region to another. The problem would be less likely with type "B" watersheds, where near-stream vegetation might have a smoothing effect on the hydrograph.

Nevertheless, aside from the effect of lower temperatures rendering "attached" nutrients in streams less readily convertible to available forms (*16*), the long-term effects of near-stream vegetation in reducing stream nutrient levels may be negligible. This is not to discourage implementation of green strips to improve stream water quality in agricultural areas. On the contrary, in many areas stream water quality problems associated with high summer maxima and large diurnal ranges in temperature and wide ranges of turbidity should be alleviated to a large degree by this practice. However unless other practices are implemented, such as reducing nutrient applications and/or adjusting the timing of these applications to maximize nutrient uptake by crops, the problems associated with high nutrient levels may be alleviated only temporarily by forested buffer strips.

Table 3. Comparisons of measured and predicted stream nutrient concentrations for watersheds with disproportionate land use patterns relative to proximity to main streams.

	Watersheds with Measured Concentrations Higher than Predicted Concentrations				*Watersheds with Measured Concentrations Lower than Predicted Concentrations*			
*Watershed Type**	*Total P*	*Ortho P*	*Total N*	*Inorg. N*	*Total P*	*Ortho P*	*Total N*	*Inorg. N*
A (Agricultural land in relatively close proximity to main streams)	13	7†	13	12	11	16†	11	12
B (Forested land in relatively close proximity to main streams)	31†	24†	29	31	24	31	27	25

*Watershed type as illustrated in figure 1.
†Measured and predicted concentrations were identical for one watershed.

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